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NBS Calibration Procedures for Horizontal Dipole Antennas (25 to 1000 MHz)

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This publication describes the theoretical basis and test procedures for horizontally polarized dipole calibrations at the National Bureau of Standards. Two different techniques and two different test sites are used. The standard antenna method uses the calculation of a field strength level, from the response of a simple half-wave dipole, to calibrate an antenna. This method is used at an open field site in the frequency range of 25 to 1000 MHz. The standard field method applies the theoretical gain equations of waveguides to determine the field strength level. This latter method is used in an anechoic chamber in the frequency range of 200 to 1000 MHz. Procedures for both techniques are explained and measurement setups are illustrated. Measurement uncertainties are discussed. Sample reports are included for both methods.

Keywords: anechoic chamber, calibration, dipole antenna, electromagnetic field, open field site, standard antenna, standard field.

1. Introduction

The purpose of this Technical Note is to provide documentation for the methods, equipment, and facilities employed by the National Bureau of Standards (NBS) for the calibration of horizontally polarized dipole antennas over the frequency range of 25 to 1000 MHz. The facilities are located in the Dept. of Commerce, Boulder Laboratories, Boulder, Colorado. The references cited are in the open literature and are available from such sources as libraries maintaining collections of scientific and technical

books and archival journals, and from the National Technical Information Service, which maintains archival collections of U. S. Government publications. Thus the material presented in this Technical Note in conjunction with the cited references provides the information necessary for the replication of the calibration procedures.

Two methods are used at NBS for horizontally polarized dipole calibrations. The standard receiving antenna method is used to calibrate continous wave (CW) field strength levels with half-wave dipole receiving antennas at the NBS open-field site. This measurement site is used over a frequency range of 25 to 1000 MHz. The standard field method is used to establish reference CW field strength levels in an anechoic chamber. The anechoic chamber can be used over the frequency range of 200 to 1000 MHz.

At the NBS open-field site, two sets of standard half-wave dipole antennas are used to measure the CW electric field strength. The field strength is calculated from the open-circuit induced voltage in the standard antenna, the transmission frequency, and the dimensions of the standard receiving dipole.

In the NBS anechoic chamber, a series of standard-gain open-ended guides (OEGs) and pyramidal horns is used for transmitting known CW electromagnetic (EM) fields. The field level is calculated from the gain of the transmitting antenna, net power delivered to the transmitting antenna, the distance from the transmitting antenna to the field point, and the effect of chamber reflections. Most of the test equipment used is commercially available. A computer-aided system can be used to automate the data collection process.

This paper presents a description of the equipment, the test method, theoretical basis of the test, and estimated errors for these standard-antenna and standard-field calibrations.

2. Standard Receiving Antenna Method [1-11]

2.1 Description of the Equipment

The NBS open-field site has two facilities for calibrating dipoles. One of these is located on a flat area of unimproved rocky soil adjacent to the wood building used for calibrating loop antennas. The other facility is designed around a grounded flat screen mesh on a slab of concrete 30 m wide and 60 m long. A tunnel under this slab leads to an underground room, approximately 3 m by 3 m, where the rf source and receiving equipment are located. Several small (15 cm diameter) tunnels leading from this room to various locations on the ground screen convey rf transmission cables and ac power cords to devices operating on or above the ground screen. The cables, being underground, do not interfere with the EM fields. The transmitting antennas are (1) horizontally polarized half-wave dipole antennas for the frequency range of 25 to 80 MHz, and (2) a horizontally polarized log-periodic antenna for frequencies from 80 to 1000 MHz. A wooden ladder with a maximum height of 6 m is used to mount the standard receiving dipole or the antenna under test (AUT) above the ground screen. Figure 1 shows the open-field site with the common locations of the transmitting and receiving antennas.

The NBS standard receiving antennas are self-resonant, half-wave dipoles with a high-impedance balanced voltmeter built across the center gap of the dipole antenna. The filtered output of the shunt-diode detector is a dc voltage that is measured by a high-impedance dc voltmeter. A photo of one of the antenna mounts (frequency range of 25 to 300 MHz) is given in figure 2. The Schottky semiconductor diode used has a low turn-on voltage and a high peak-reverse voltage rating of 70 V [5]. This type of diode provides a very high shunt impedence (>100 MΩ) for the signal levels used in NBS calibrations. The filter consists of four resistors and two capacitors.

The high-resistance lines below the filter in figure 2 are made of carbon-impregnated plastic, coated with a nylon jacket. Each line has a resistance of about 600 Ω/cm.

The transmitted signal is produced by a combination of signal generators, amplifiers, low-pass filters, low-loss transmission lines, and a transmitting antenna. Figure 1 shows the equipment used for a measurement test at the open field site. The rf voltmeter is used to monitor the level of the transmitter voltage. A generic list of equipment used on the ground screen is given in table 1. The cables are 50 Ω coaxial with type N connectors.

The open-circuit rf voltage of the standard dipole can be determined if the relation of input rf voltage to output dc voltage is known. The rf-to-dc voltage curve of a standard dipole antenna is obtained by injecting known rf voltages across the dipole mount at 50 MHz and measuring the detected dc responses from the output of the mount. The response of each dipole mount is essentially independent of frequency over the frequency range used. The frequency of 50 MHz was chosen because it is high enough to give the correct calibration, yet low enough to avoid error caused by transformation of voltage in the short "transmission line" between the modified tee connector and the dipole mount (see figure 3). Also, 50 MHz is the frequency of the internal calibrating source used in the 50 Ω power meter shown for measuring rf voltage at the tee connector. Figure 3 shows the test setup for this measurement. The equation for the curve of rf input voltage to dc output voltage is used to calculate the open circuit rf voltage across the center gap of the standard dipole. A typical curve is given in figure 4.

2.2 Test Procedure

NBS tests dipoles and other field strength measuring devices at specified frequencies, field strength levels, heights above ground, and distances between transmitting and receiving antennas. When a device to be

tested arrives, the serial numbers are logged, a test number is assigned, and a test folder is issued. The unit is inspected to see if it is operating correctly. Before the actual testing is done, a review of the anticipated data and the procedure details are decided upon. The test data are usually reported in terms of the antenna factor or antenna output, such as detected dc voltage.

An EM field is generated by a transmitting antenna at the open field site. An NBS standard dipole antenna is used as the receiving antenna, and the detected dc voltage is measured with a high impedance (100 MΩ) voltmeter. The transmitter voltage level is monitored with an rf voltmeter to ensure that it does not change during the test. The AUT is then substituted at the same position as the NBS standard dipole. The rf output of the AUT is measured with a calibrated 50 Ω spectrum analyzer or 50 Ω power meter. Data for the rf-to-dc curve of the standard dipole mount are measured before and after each test. The insertion loss of the cables used is also measured before and after each test to insure that the cable and connector losses are repeatable. The antenna factor is determined from these measurements, as described in section 2.3.

The transmitting antenna is mounted on a tripod and the height set to a specified value, usually 3 m. The vertical wooden ladder for supporting the receiving antennas is mounted directly over the underground room. If the distance between the transmitting and receiving antennas is not specified, the distance is usually set between 15 and 20 m. In order to produce a uniform wavefront at the receiving antenna, this separation distance should be at least two wavelengths at the operating frequency. If the antenna height above ground is not specified, the height of both receiving antennas (standard dipole and AUT) is set to 3 m. This height is usually sufficient to reduce calibration errors caused by impedance changes in the AUT, which are due to the proximity of the natural ground or conducting ground screen beneath the antenna [2-3]. If the AUT is adjustable in length, its length

is set to the value specified by the customer (usually an electrical half wavelength).

The equipment used is connected as shown in figure 1. The power meters with their appropriate sensors are calibrated by the NBS power calibration services. The spectrum analyzer is calibrated by the NBS microwave calibration service (test 61190S)[40], and verified before each test by means of calibrated power meters.

All of the serial numbers on the AUT and equipment used are recorded, and a sketch is made of the calibration setup. If the test requires an unusual arrangement, a photograph of the system is taken. Header titles are written for each column of data to be taken (along with units), and any other pertinent information is noted on the data sheet. A sample data sheet is given in figure 5.

The NBS standard dipoles used to measure the incident field (E_{inc}) lack frequency selectivity, so it is not possible to perform a calibration in the presence of strong interfering signals. Therefore the detected ambient signal level is recorded. That is, the level of the dc voltage output of the standard dipole with no NBS test signal applied is noted on the data sheet. This level is usually less than 5 mV. The range of dc output voltages used at NBS for field strength calibrations is normally 0.5 to 1.5 V, which is sufficiently high to avoid calibration uncertainty caused by ambient signals and noise or by changes in ambient temperature. The rf-to-dc calibration of the dipole mount depends slightly on the diode temperature, especially at low signal levels. This uncertainty is negligible for detected voltages greater than 0.5 V, if the temperature is within $\pm$ 10^{0}C of that for which the diode was calibrated.

2.3 Theoretical Basis of the Test

An NBS standard half-wave dipole is used to determine the calibrating field strength level from the relation

$$E_{inc} = \frac{V_{oc}}{L_{eff}} \qquad (1)$$

where E_{inc} = electric field strength of the locally generated field, V/m,
V_{oc} = open-circuit rf voltage induced in the standard dipole, V, and
L_{eff} = effective length of the standard dipole, m.

The theoretical effective length of an infinitesimally thin half-wave dipole in free space is given by

$$L_{eff} = \lambda / \pi \qquad (2)$$

where λ = free space wavelength, m.

The NBS standard dipoles have a cylindrical shape. An approximate solution for their effective length and required shortening for self resonance was derived by Schelkunoff [1]. The required length depends on the dipole length-to-diameter ratio, and is given approximately by

$$\text{Required } L \approx \left(\frac{\lambda}{2}\right) \left[1 - \frac{0.2257}{\ln(\lambda/D)-1}\right] \qquad (3)$$

where Required L = length of the cylindrical standard dipole required for self resonance, m, and
D = diameter of the standard dipole, m.

The NBS standard dipoles consist of a center mount, as shown in figure 2, to which extension rods are attached. One pair of rods is available to

achieve a self-resonant length at each calibration frequency [2-4]. The effective length of a thin cylindrical dipole having a length near self resonance is given by

$$L_{eff} = (\frac{\lambda}{\pi}) \tan (\pi L/2\lambda) \tag{4}$$

where L_{eff} = effective length of the dipole, m, and
L = measured tip-to-tip length of the dipole, m.

The open-circuit rf voltage of the NBS standard dipole is determined from the measured dc voltage by applying the equation

$$V_{oc} = M(V_{det}) + B \tag{5}$$

where V_{oc} = open-circuit rf voltage across the dipole center gap, V,
M = slope of the rf input to dc output curve, measured over the voltage range of 0.5 to 2 V (see figure 4),
V_{det} = detected dc voltage of the standard dipole, V, and
B = y intercept of the rf-to-dc calibration curve.

The value of the calibrating electric field, E_{inc} is now obtained from eq (1) using the solutions of eqs (4) and (5). Once the electric field strength is known, the antenna factor of the AUT is calculated from the expression

$$K = (E_{inc}) - (V_{50\ \Omega}) - A \tag{6}$$

where K = antenna factor of the AUT, dB,
E_{inc} = calibrating field strength level, dBmV/m,
$V_{50\Omega}$ = AUT voltage pickup, dBmV, and
A = cable attenuation between the AUT and the 50 Ω receiver, dB.

2.4 Estimate of Calibration Uncertainty [6,7]

For calibrations at the NBS open field site, at frequencies of 25 to 1000 MHz, the following statements give the possible errors of a measurement

(1) One source of error in the calibration is uncertainty of the calibrating field value at the open field site. This is due mainly to uncertainty in the dc-to-rf voltage transfer. Also, signals from radio stations and 2-way radio communications may cause extra errors. The estimated error is ± 0.4 dB.

(2) Another source of error is uncertainty in the disturbance of the field caused by interconnecting cables and nearby buildings. This error is estimated to be less than ± 0.2 dB.

(3) Other sources of uncertainty are associated with antenna alignment, measurement of antenna separation distance, and NBS calibrations of the various instruments used. These include spectrum analyzers, rf voltmeters, and power monitors. The error due to these last sources is estimated to be less than ± 0.4 dB.

The overall worst-case uncertainty of an antenna calibration is the simple sum of those listed, or ± 1 dB.

Table 1. List of equipment used for the open-field site test.

- synthesized signal generator, +3 dBm maximum output, 10 kHz-1000 MHz
- amplifier, 1-1000 MHz, 50 W output
- amplifier, 1-1000 MHz, 3 W output
- ac voltmeter, with coaxial tee connector
- dc voltmeter, high input impedence (100 MΩ)
- calibrated power meter, single sensor capability
- power sensors: 100 mW capacity
- calibrated spectrum analyzer, covering the frequency range of 25 to 1000 MHz
- assorted filters, attenuator pads, and low loss cables with type N connectors.

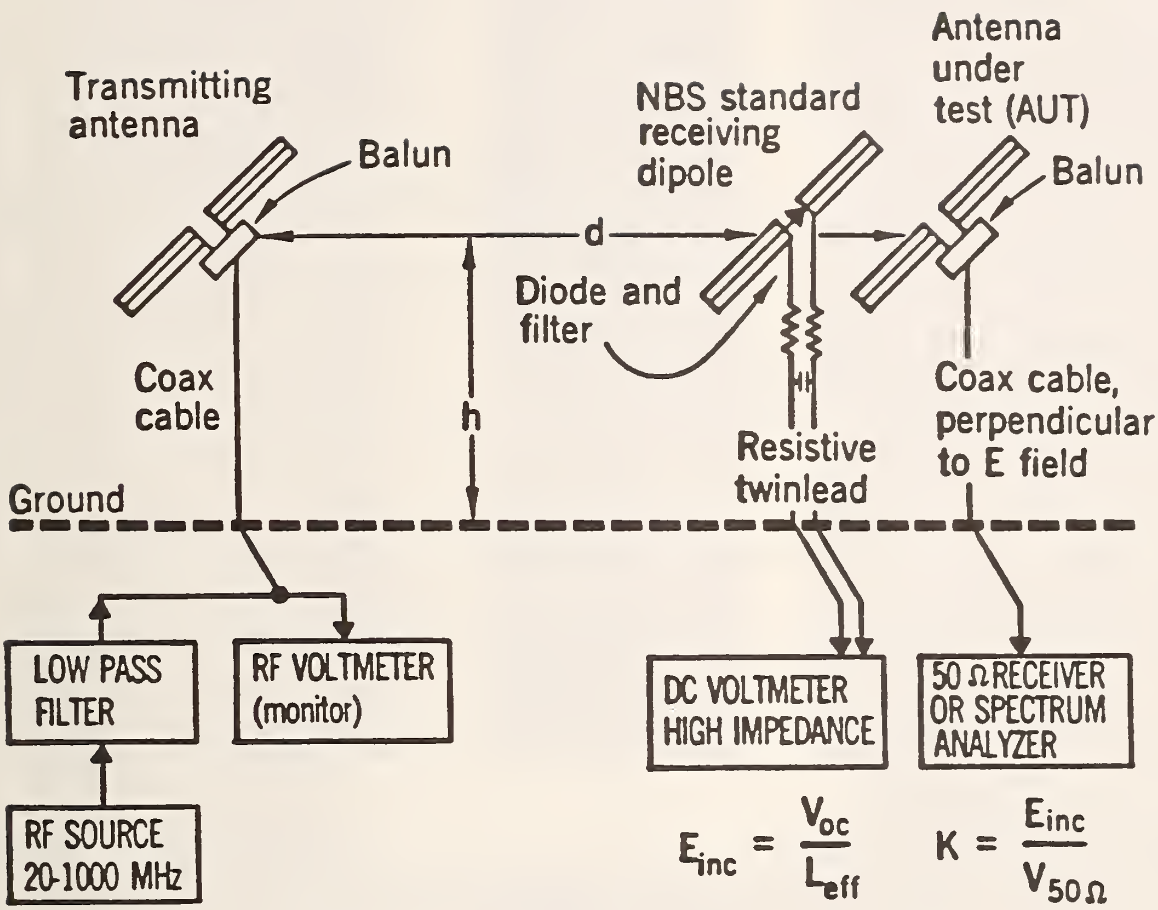

Figure 1. Field site instrumentation for calibrating horizontal dipoles, at frequencies of 25 to 1000 MHz.

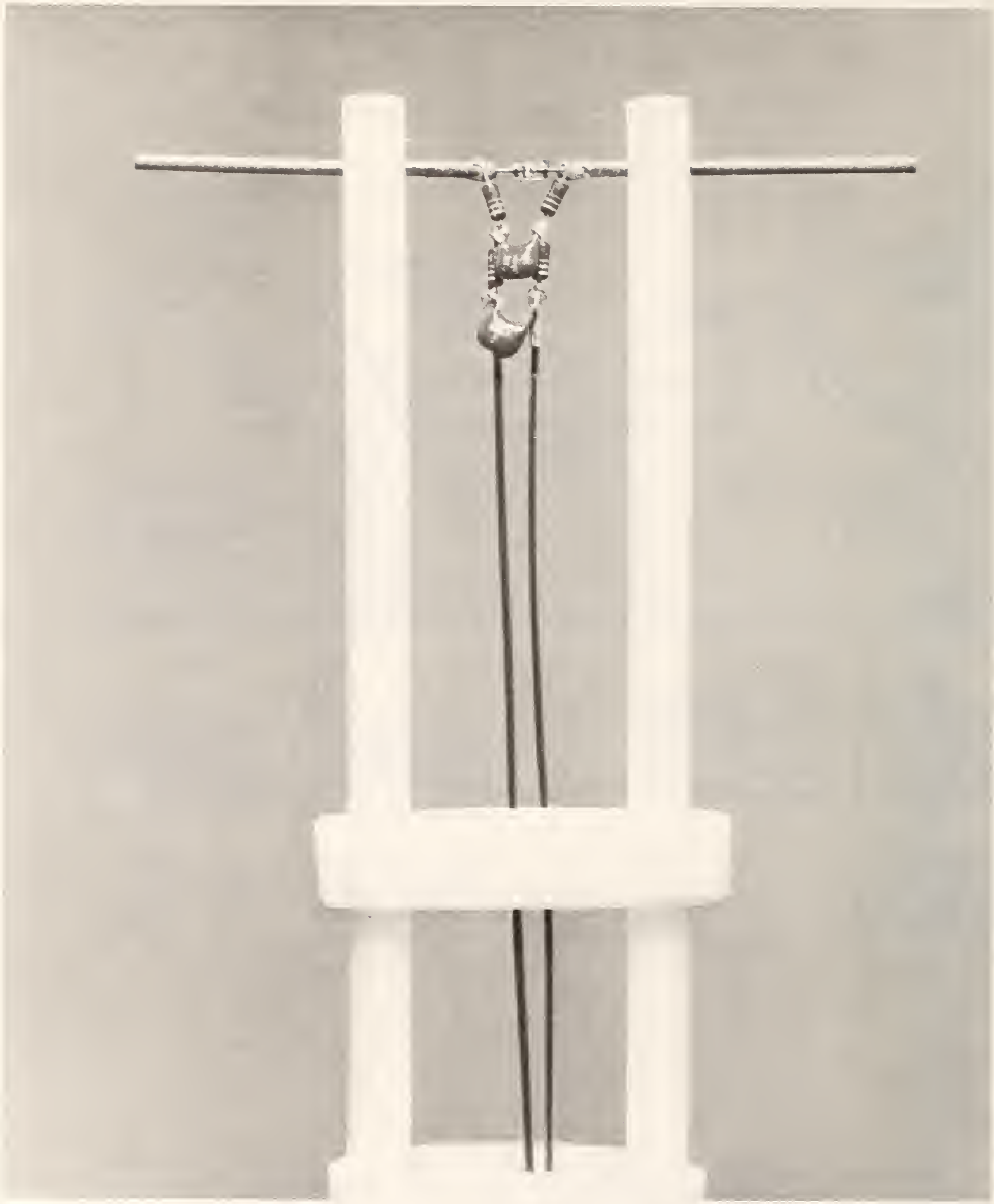

Figure 2. Standard receiving dipole mount with diode detector, filter, and resistive transmission line.

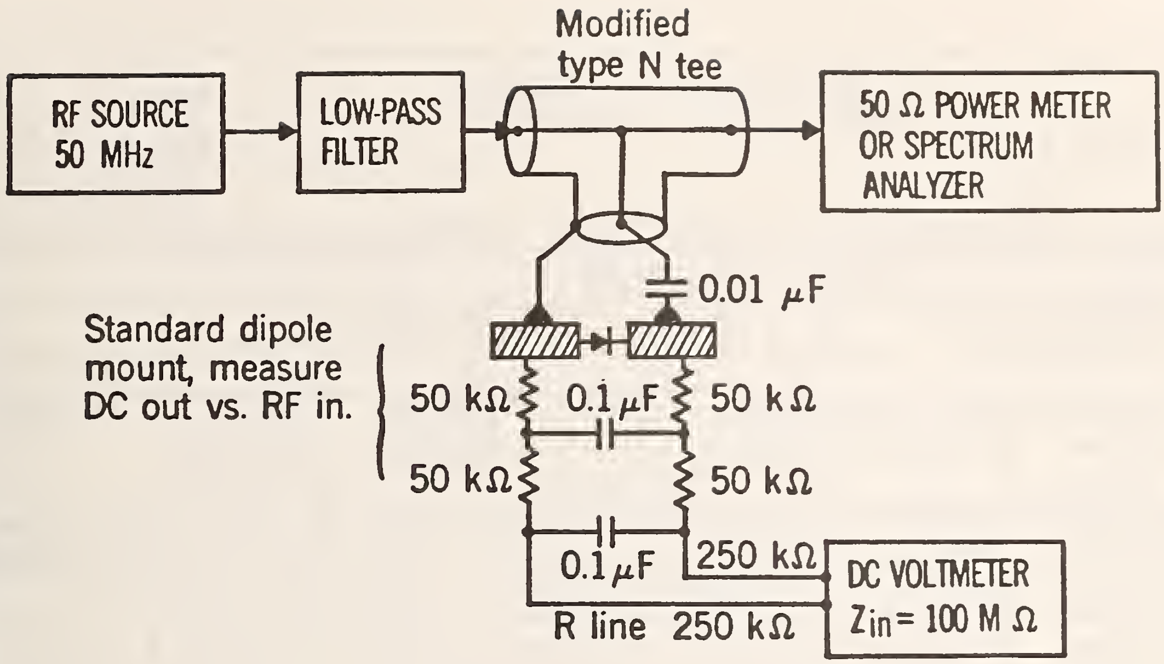

Figure 3. Instrumentation for measuring V_{oc} versus V_{dc} of the NBS standard dipole.

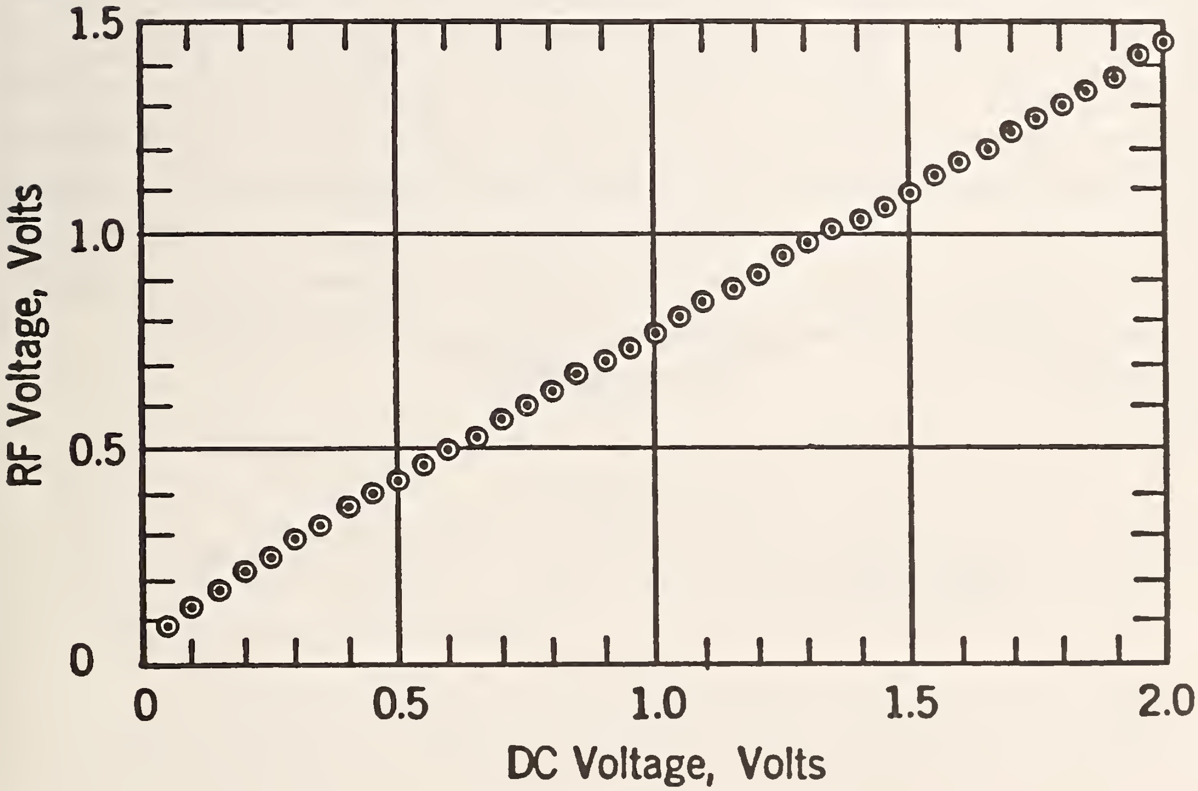

Figure 4. Typical calibration curve of a standard dipole mount, showing the dc voltage versus rf voltage relation.

LOG SHEET
(Sample Only)

U. S. DEPARTMENT OF COMMERCE
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DATE ________

SHEET NO. 1 of 1

OBSERVER ________

KIND OF MEASUREMENT Biconical & Log Periodic Antennas; SN ØØ1 & ØØ2

INSTRUMENT TESTED XYZ Company

$h_T = 3$ m $h_R = 3$ m dist = 20 m

Frequency (MHz)	Low. Pass Filter (MHz)	RF voltage -monitor- (V)	Standard Dipole Output-dc (mV)	AUT output (dBm)	Standard Dipole Output-dc (mV)	Standard dipole Ambient before/after (mV)	Comments
25	30	40.3	1200	-11.20	1184	30/20	Biconical
50	70	86.3	805	-9.35	805	20/24	↓
100	110	12.4	1896	3.35	1894	15/17	
200	250	60.6	1285	-0.25	1280	1/1	
500	500	16.2	1299	1.65	1301	4/3	Log Periodic
1000	1000	46.6	1095	-1.00	1106	5/3	↓

Figure 5. Sample data sheet for dipole measurements at the NBS open field site.

3. Standard Field Method [7-39]

3.1 Description of the Equipment

The NBS anechoic chamber is constructed within a metal shielded room 5 m high, 6.7 m wide, and 8.5 m long. The chamber is lined with absorbing material on all of the inside walls, ceiling, and floor. An equipment cart placed on a precision track is movable over the entire length of the chamber. The cart is 1.9 m wide by 0.75 m deep, with pieces of absorber mounted on the front side. The cart is driven by a stepping motor that steps in minimum increments of 2 mm. A rotator/positioner can be placed on the cart for axial rotation and positioning of the AUT. A doorway 1.2 m wide, in line with the track, provides access into the chamber. Figure 6 shows a side view of the anechoic chamber, cart, and doorway.

Fiber optic cables are connected from the equipment cart through the chamber doorway to a computer in the laboratory. The fiber optic lines are essentially transparent to the rf energy and provide negligible interference with the generated fields. On the cart is a single-board computer which is used to process and transfer information through the fiber optic lines. This information consists of data from the AUT, instructions for movement of the cart, and instructions for turning the rotator.

A pyramidal horn or rectangular OEG is used as a transmitting antenna, and positioned near the chamber entry region on the measurement axis. A series of two pyramidal horns and two OEGs is available to establish known EM fields in the chamber. These horns and OEGs cover the frequency range of 200 to 1000 MHz. A sketch of an OEG is given in figure 7 and a sketch of a horn is given in figure 8. Table 2 lists each horn or OEG with its frequency range and dimensions.

The transmitted signal is produced from a combination of signal generators, amplifiers, low-pass filters, and low-loss transmission lines.

Figure 9 shows the equipment used for a measurement test in the anechoic chamber. Measurement of the net transmitting power is done with a dual directional coupler and two power meters with thermistor sensors. When measurements of high power are done, calibrated attenuators can be inserted in the coupler secondary ports to assure the power level is within the sensors' range. A generic list of equipment used in the anechoic chamber is given in table 3. The cables are 50 Ω coaxial with type N connectors.

3.2 Test Procedure

For anechoic chamber measurements, the AUT is mounted on the movable cart and aligned along the center axis of the transmitting antenna. Dielectric supports are used to mount the AUT in line with the axis of the transmitting antenna. A laser alignment system located outside the chamber is used to align the AUT and transmitting antenna on the measurement axis. If a rotator/positioner is used, it is placed on the cart and the AUT is mounted on the rotator and aligned on axis of the transmitting antenna.

The following steps are used to align the transmitting horn or OEG with the AUT

(1) The laser system is leveled and placed on the measurement axis.

(2) The AUT is placed on the cart and the laser is used to align the AUT on axis.

(3) The appropriate transmitting horn or OEG is placed on a cart outside of the chamber doorway.

(4) The transmitting antenna is aligned using the laser, with the AUT positioned in the chamber.

The equipment for each frequency is connected as shown in figure 9. The power meters and appropriate sensors are calibrated units, having been calibrated by the NBS microwave calibration service (test 61190S)[40]. All

of the serial numbers on the AUT and the equipment used are recorded and a sketch is made of the setup. If the test is an uncommon arrangement, photographs are taken.

There are two techniques available to test the AUT. One is to set the field strength at a prescribed level and then record the response of the AUT. The output of the AUT is recorded as a function of applied field strength. Most of the tests performed at NBS are done using this first technique. The other technique is to adjust the field level until the AUT is at the desired response and then record the field level necessary to achieve that response. The level of the standard EM field necessary for this indication is calculated with the help of a computer in terms of the known gain of the transmitting horn and the net delivered power, as described in section 3.3. To determine the value of the net power, the incident and reflected power are measured at the secondary ports of the dual directional coupler. The calibrated values of the coupler losses are also used to calculate the net power, as described in section 3.3.3.

The measurement data can be collected and processed automatically. Figure 10 shows the NBS system that is under computer control. Frequency and field level are selected as needed for the test. The computer controls the movement of the cart and rotation of the rotator. The amplifiers and filters are selected by a series of rf switches. The IEEE-488 bus is used for most of the data and command transfer. The computer is also used to print out the data and all pertinent information. The amount of automation used depends on the amount of data and the format in which the data is requested. If only a few data points are needed, the manual method may be more efficient.

The manual method of collecting data uses the computer to calculate the power necessary to create a desired field strength level in the anechoic chamber at the AUT, as described in section 3.3. The operator connects the

system as shown in figure 9. Power is applied at the test frequency as calculated by the computer. The response of the AUT is recorded from the appropriate metering unit. The metering unit may be a dc voltmeter, spectrum analyzer, power meter, etc. depending on the output of the AUT.

On completion of the test, the data are compared with theoretical computations, the data history of the AUT (if any), and/or the data history of the anechoic chamber. If the data do not agree with anticipated results, the AUT and/or the NBS measurement system are checked. If the AUT is suspected of being defective, arrangements are made to check and repair it, if possible. Most data are plotted with graphic routines available on the computer system. A sample of an NBS test report is given in appendix B. Different report formats are written for each type of calibration depending on the requested type of measurement.

3.3 Theoretical Basis of the Test

The standard field method used at NBS in the anechoic chamber involves calculating the radiated intensity in the near zone of standard gain antennas. This method consists of generating and computing the desired component of a field in terms of the dimensions and shape of a transmitting antenna, net delivered power, the distance from the transmitting antenna to the AUT, and the effect of chamber reflections. A set of two rectangular OEGs is available to cover the 200 to 500 MHz frequency range, while a set of two rectangular pyramidal horns is used from 450 to 1000 MHz.

The on-axis field intensity is calculated in terms of the net power delivered to the transmitting antenna and the calibrated gain of the pyramidal horn or OEG "launcher". The field intensity in the center of the beam is calculated, at each frequency, using power equation techniques. All of the instrumentation is readily available commercially except for the

large OEG launchers. These OEGs were made of sheet metal to the dimensions specified in table 2. The value of standard field is given by [32]

$$E = \frac{\sqrt{30\ PG}}{d} \tag{7}$$

where
E = on-axis magnitude of the radiated field, V/m,
P = net power delivered to the transmitting horn or OEG, W,
G = calibrated gain of the transmitting antenna, including appropriate near-zone correction factors, and
d = distance from the horn or OEG aperture to the calibrating field point (center of dipole), m.

The effects of multipath reflections in the anechoic chamber have been analyzed and taken into account for each setup and frequency [32,34].

3.3.1 Gain of Open-Ended Guides, 200 to 500 MHz

Early work to determine the field pattern and gain of OEG radiators, both theoretically and experimentally, is described in [6], and later derivations are given in [20]. An equation giving the gain of an open-ended waveguide as a function of frequency and aperture dimensions has been determined experimentally at NBS. The original data for this equation came from a two-antenna calibration technique using two "identical" open-ended guides [13]. Further calibrations have been made with the two specially-fabricated OEGs, each having a length of about 2 m. All of the OEGs used at NBS have a 2-to-1 aspect ratio. In this case, the equation for calculating the antenna gain is [32]

$$\text{GAIN} = 21.6\ Fw, \text{ or} \tag{8a}$$

$$\text{GAIN, dB} = 10 \log (Fw) + 13.34, \tag{8b}$$

where F = frequency, GHz, and

w = width (larger side) of the 2-to-1 OEG, m.

Equation (8) is accurate to ± 0.5 dB if the distance, d, from the OEG aperture to the field point is greater than double the width, w. Figure 7 shows the dimensions used in the equation. Figure 11 is a plot of the theoretical gain from eq (10) and the measured gain values in the anechoic chamber as a function of distance from the OEG aperture.

3.3.2 Gain of Pyramidal Horns, 450 MHz to 1 GHz

Standard fields above 450 MHz are produced in the anechoic chamber by a series of standard-gain pyramidal horns. A complication known as near-zone gain reduction applies to the calculation of field strength when the AUT is very close to a transmitting antenna. Simple polynomial expressions have been derived at NBS to determine the near-zone gain-reduction factors, R_H and R_E, for pyramidal horns [29,32]. The pertinent horn dimensions used in the equations are shown in figure 8. The procedure involves a computation of the intensity produced by an in-phase aperture and then applying two near-zone correction factors. The values of these gain-reduction factors depend on frequency, horn dimensions, and distance to the on-axis field point. The two gain-reduction factors, R_H and R_E, are given by

$$R_H = (0.01\alpha)\,(1 + 10.19\alpha + 0.51\alpha^2 - 0.097\alpha^3), \qquad (9a)$$

$$R_E = (0.1\beta^2)\,(2.31 + 0.053\beta), \qquad (9b)$$

where $\alpha = \left(\frac{a^2F}{0.3}\right)\left(\frac{1}{l_H} + \frac{1}{d}\right)$ and $\beta = \left(\frac{b^2F}{0.3}\right)\left(\frac{1}{l_E} + \frac{1}{d}\right)$,

a, b, l_H and l_E = horn dimensions of table 2, m,

F = frequency, GHz, and

d = distance from the horn aperture to the field point, m.

The theoretical gain of the horn, near zone or far zone, is given by

$$\text{GAIN} = (113.3\ a\ b\ F^2)[10^{(-R_H - R_E)}], \text{ or} \qquad (10a)$$

$$\text{GAIN, dB} = 10 \log (ab) + 20 \log F + 20.54 - R_H - R_E. \qquad (10b)$$

These equations have been checked experimentally using several different standard-gain horns covering the frequency range of 450 MHz to 4 GHz. The horns were also calibrated at NBS by the three-antenna method [18,23,26,28,30,39] and these gains were compared with that given by eq (10). For distances greater than 0.5 m, the difference between the experimentally calibrated gain and the value calculated from eq (10b) was less than 0.5 dB. A plot of horn gain vs. distance is shown in figure 12, comparing the theoretical curve with measurements made in the NBS anechoic chamber.

3.3.3 Net Power

The calculation of the net power delivered to the pyramidal horn or OEG depends on the values of incident power and reflected power measurements in the dual-directional coupler secondary ports. This net power is given by

$$P_{net} = P_{inc}[10^{C_i/10}] - P_{refl}[10^{C_r/10}] \qquad (11)$$

where
- P_{net} = net power delivered to the transmitting horn or OEG, W,
- P_{inc} = power measured in the incident arm of the coupler, W,
- C_i = coupling ratio from the output port to the incident arm of the coupler, dB,
- P_{refl} = power measured in the reflected arm of the coupler, W, and
- C_r = coupling ratio from the output port to the reflected arm of the coupler, dB.

3.4 Estimate of Calibration Uncertainty

For frequencies from 200 to 1000 MHz, horizontally polarized dipoles can be calibrated in the NBS anechoic chamber. The following statements give the possible errors of a measurement

(1) The largest source of error is caused by uncertainty in the near-zone gain value of the transmitting antenna. The estimated possible error is ± 0.5 dB.

(2) Another source of error is uncertainty in the magnitude of multipath reflections within the anechoic chamber. Possible errors caused by chamber reflections are estimated to be less than ± 0.2 dB.

(3) Other sources of uncertainty are associated with antenna alignment, measurement of antenna separation distance, and NBS calibrations of the various instruments used. These include directional couplers, and incident and reflected power monitors. The overall error due to these latter sources is estimated to be less than ± 0.3 dB.

The overall worst-case uncertainty of the measurement is the simple sum of those listed, or ± 1 dB.

Table 2. Pyramidal horns and OEGs for the anechoic chamber (200 to 1000 MHz)

ANTENNA	FREQUENCY RANGE (MHz)	a (m)	b (m)	l_H (m)	l_E (m)
WR-3600 OEG	180 to 310	0.9144	0.4572	NA	NA
WR-2100 OEG	310 to 530	0.5334	0.2567	NA	NA
SA 12-0.5 #48	450 to 750	1.2250	0.9075	1.420	1.213
SA 12-0.75 #57	700 to 1100	0.8278	0.6118	0.943	0.812

Table 3. List of equipment for the NBS anechoic chamber.

- computer with disk drives
- synthesized signal generator, +3 dBm maximum output, 100-1000 MHz
- amplifier, 1-1000 MHz, 50 W output
- amplifier, 1-1000 MHz, 3 W output
- dual directional coupler, 0.1-2 GHz, 50 W capacity
- calibrated power meter, single sensor capability
- calibrated power meter, dual sensor capability
- power sensors: 10 μW, 100 mW, 3 W, maximum capacity
- calibrated spectrum analyzer, covering the frequency range of 200 to 1000 MHz
- assorted filters, attenuators, and type N cables

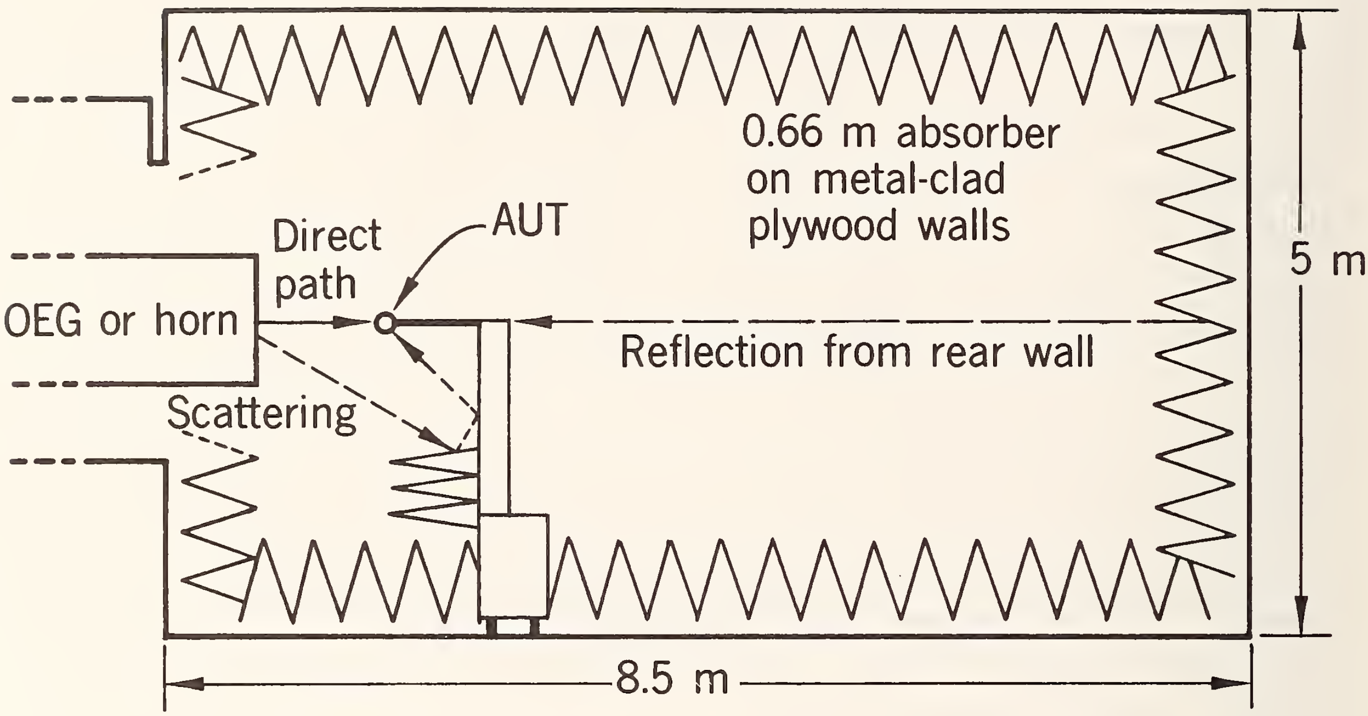

Figure 6. Side view of the NBS anechoic chamber.

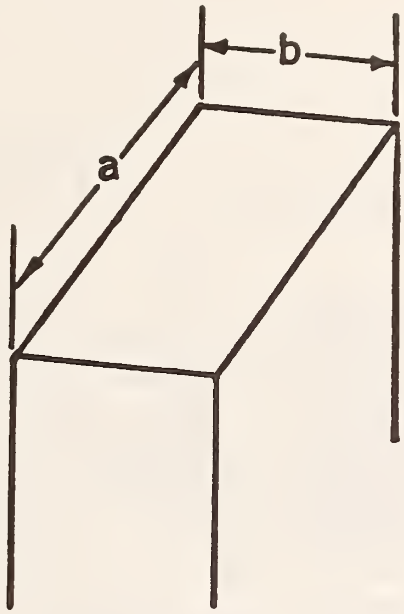

Figure 7. Geometry of open-ended rectangular waveguide.

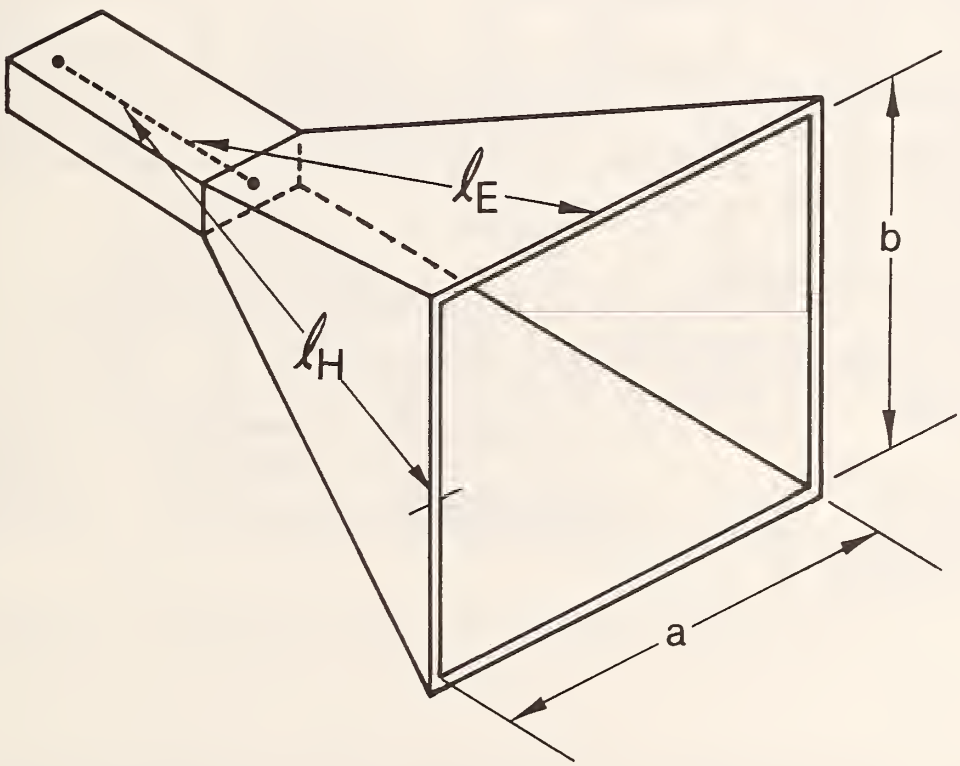

Figure 8. Sketch of a pyramidal horn showing the dimensions.

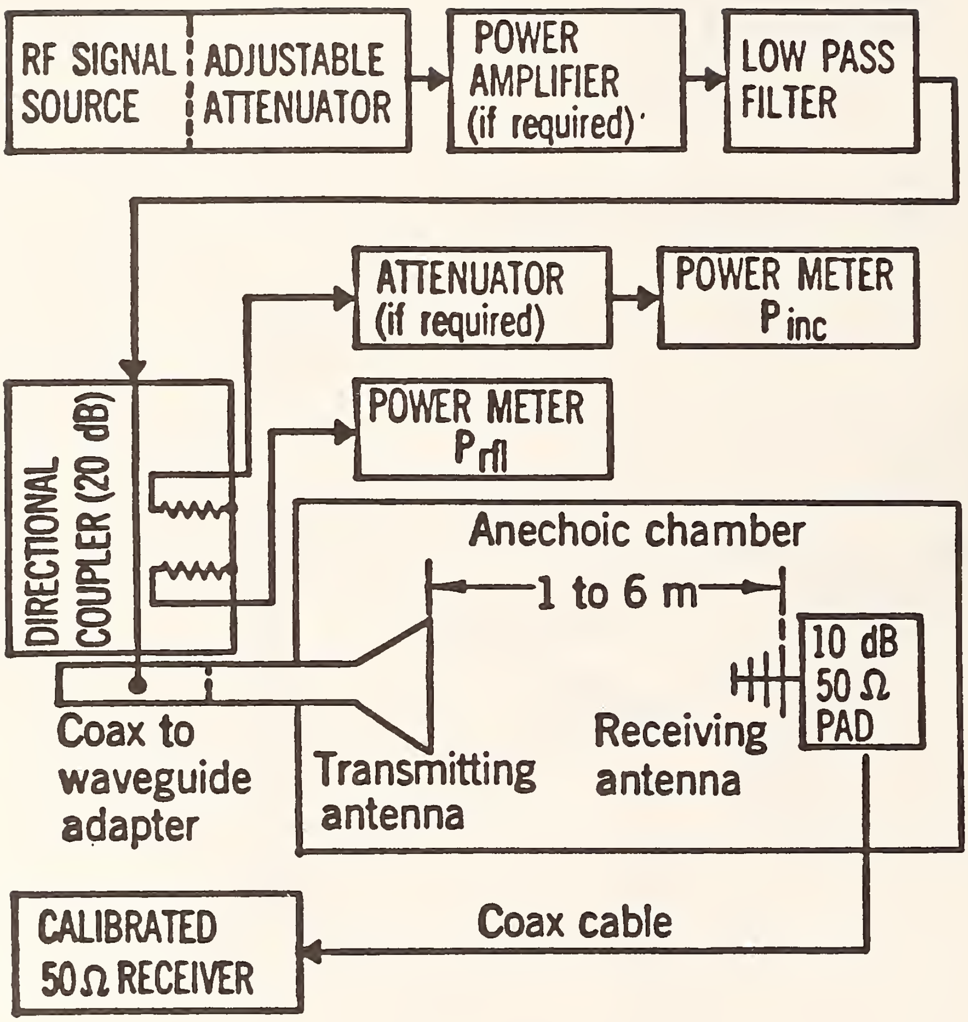

Figure 9. Instrumentation for generating a standard field in an anechoic chamber.

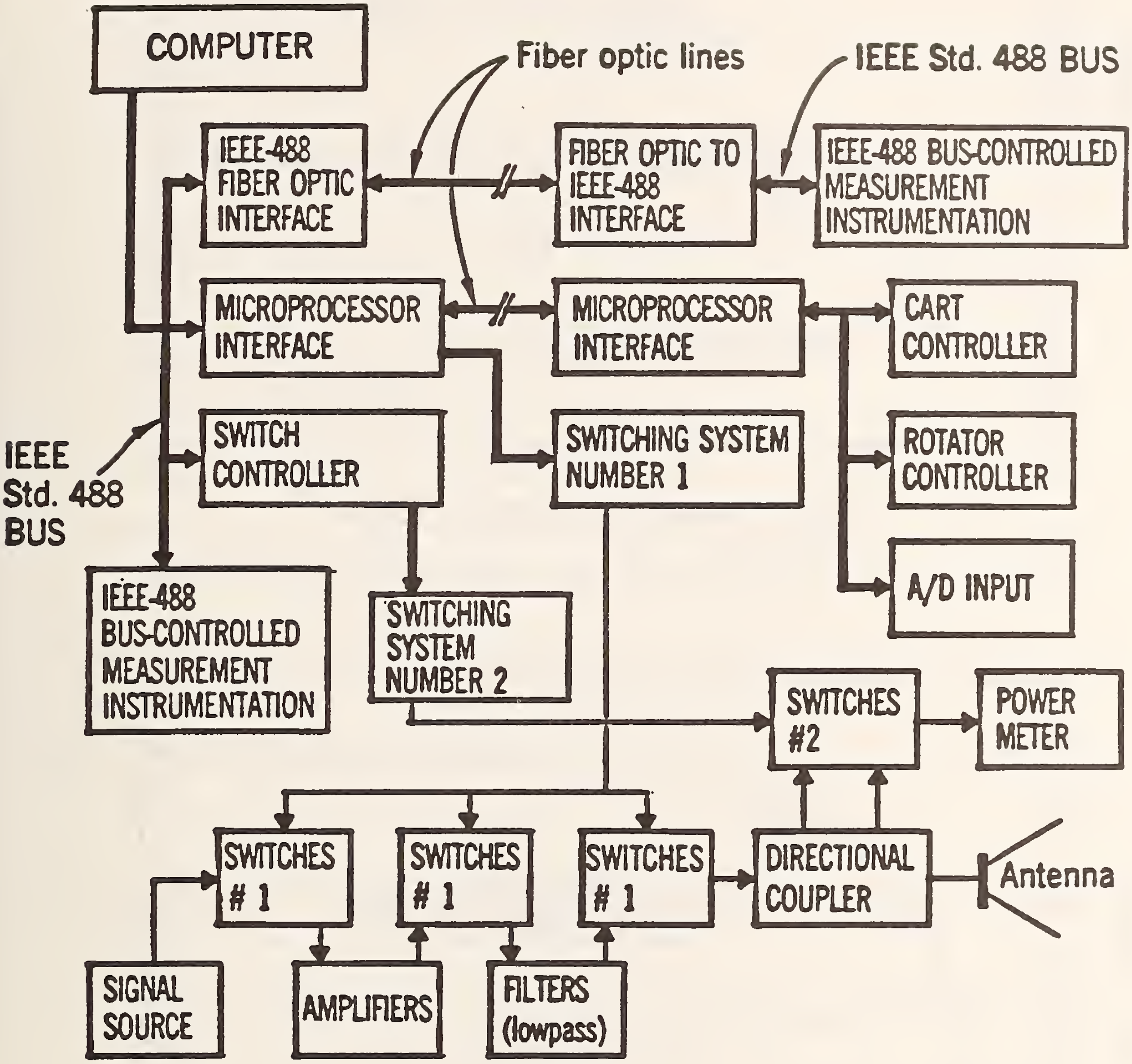

Figure 10. Automated system for the NBS anechoic chamber.

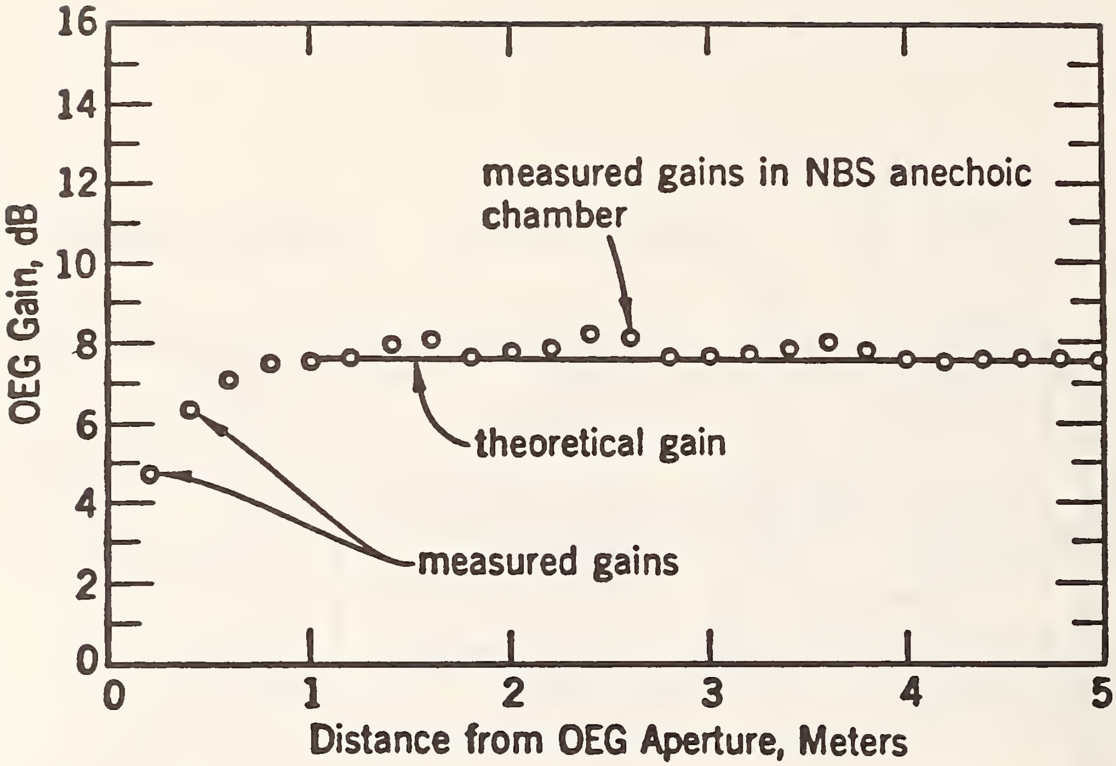

Figure 11. Graph of WR-2100 OEG gain versus distance at 500 MHz.

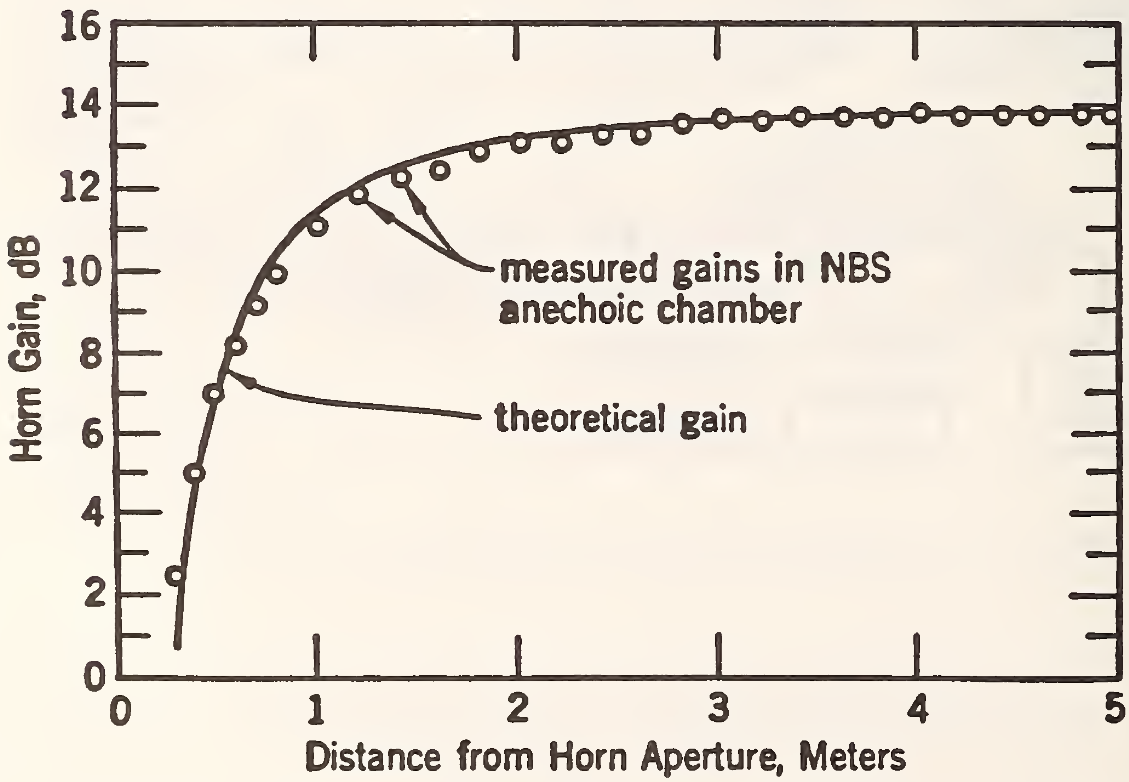

Figure 12. Graph of SA 12-0.5 horn gain versus distance at 500 MHz.

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5. APPENDIX A : Sample test report for standard antenna method.

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
NATIONAL ENGINEERING LABORATORY
Boulder, Colorado 80303

SPECIAL TEST

DIPOLE ANTENNA
Manufacturing Company Name
Model ____, Serial No. ____

Submitted by:

Requesting Company/Agency Name
City, State, Zip code

I. Introduction

The tunable dipole antenna from the requesting company is for measuring horizontally polarized electric fields. The antenna, Model ____, is intended for use in the 20 to 300 MHz frequency range.The calibration data given in this report are not necessarily applicable to measurement of impulsive fields.

II. Description of the Tests

At 300 MHz and lower frequencies, horizontally polarized dipole antennas are calibrated at the ground screen site using the standard antenna method described by Taggart and Workman [1].

The calibration is performed by radiating a horizontally-polarized field of convenient magnitude from a dipole or log periodic antenna. A standard receiving antenna capable of accurately measuring the magnitude of this field is placed in the far-field at a fixed height above the ground, and the magnitude of the electric field is measured. The transmitting antenna power is held at a constant level, and the antenna being calibrated is substituted in place of the standard antenna. Figure 1 (see figure 1 in this Tech. Note) shows a diagram of the instrumentation used.

The NBS standard receiving antenna consists of a self-resonant, half-wave dipole antenna with a high impedance balanced voltmeter built into the center of the antenna. The balanced voltmeter is composed of a diode detector and an R-C filter network. The dc output of the filter is measured with a high impedance voltmeter. The antenna voltmeter dc-to-rf voltage transfer function is measured, and from the dc output of the antenna the rf voltage at the essentially open-circuit dipole terminals is determined.

Test No. __________
Date of Test: ____________

The resulting incident field strength at the measurement location is obtained using the following two equations:

$$L_{eff} = (\lambda/\pi) \tan (\pi L/2\lambda) \tag{1}$$

$$E_{inc} = V_{oc}/L_{eff} \tag{2}$$

where

L_{eff} = dipole effective length, m,

λ = free-space wavelength, m,

L = length of standard dipole, m,

V_{oc} = open-circuit standard dipole voltage, V,

E_{inc} = calibrating incident field strength, V/m.

The antenna factor is the ratio of the field strength to the rf voltage from the antenna being calibrated, delivered to a 50-ohm receiver. Note that a lossless 50-ohm transmission line to the antenna being calibrated is implied in this definition of antenna factor.

III. Experimental Data

An electric field strength can be determined with the calibrated dipole antenna by measuring the output voltage of the antenna when connected to a 50-ohm impedance and using the following equation:

$$E = K + V \tag{3}$$

where

E = unknown electric field strength, dBV/m,

K = antenna factor, dB, and

Dipole Antenna
Manufacturing Company Name
Model ____, Serial No. ____

V = output voltage of the antenna, dBV.

Note: Units of dBμV/m and dBμV may also be used in the above equation for E and V, respectively, if desired.

The measured values of antenna factor for the dipole antenna are given in the following table. These values are for the antenna alone, independent of any interconnecting cable loss. The height above ground was 3 meters.

Table 1. Antenna Factor for Dipole Antenna, Model ____, SN _____.

Frequency MHz	Antenna Factor dB
25	9.0
30	10.5
40	12.0
50	14.0
60	15.5
70	17.0
80	18.2
90	19.3
100	21.1
125	22.4
150	23.1
175	24.3
200	25.7
250	26.4
300	27.0

IV. Calibration Uncertainties

For frequencies up to 300 MHz, the dipole antenna is calibrated at the ground screen site. The electromagnetic field levels are sufficient to indicate the requested calibrating field strength at the antenna.

1. The largest source of error in the calibration is uncertainty of the standard field value at the ground screen site. This is due partly to uncertainty in the dc-to-rf voltage transfer. Also, signals from radio stations, CB's, and 2-way radio communications may cause extra errors. The estimated possible error is ±0.4 dB.

2. Another source of error is uncertainty in the disturbance of the field caused by interconnecting cables and nearby buildings. This error is estimated to be less than ±0.3 dB.

3. Other sources of uncertainty are associated with antenna alignment, measurement of antenna separation distance, and NBS calibrations of the various instruments used. These include spectrum analyzers, rf voltmeters, and power monitors. The error due to these latter sources is estimated to be less than ±0.3 dB.

The overall worst-case uncertainty of the calibration is the simple sum of those listed, or ±1 dB.

When an antenna is used in an actual measurement situation, an additional error may occur. The value of K is measured for the antenna at a specified height above ground. Use of the calibrated antenna later at a different height or over ground having different constants may cuase an error, for heights less than about 1λ. This is because the source impedance of the customer's antenna depends on its height above ground, which may lead to measurement error for the usual case where the antenna is loaded by a 50-ohm receiver. A change of impedance doesn't affect the measurement of V_{OC} by the open-circuit standard dipole, but it changes the mismatch between the customer's antenna and 50-ohm receiver. This error is generally less than 0.5 dB for heights greater than $\lambda/2$.

V. References

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For the Director,
National Engineering Laboratory

Motohisa Kanda, Ph.D.
Group Leader, 723.03
Fields Characterization Group
Electromagnetic Fields Division

6. APPENDIX B : Sample test report for standard field method.

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
NATIONAL ENGINEERING LABORATORY
Boulder, Colorado 80303

SPECIAL TEST

DIPOLE ANTENNA
Manufacturing Company Name
Model No. ____, Serial No. ____

Submitted by:

Requesting Company/Agency Name
City, State, Zip code

I. Introduction

The tunable dipole antenna from the requesting company is for measuring horizontally polarized electric fields. The antenna, Model ____, is intended for use in the 200 to 1000 MHz frequency range. The calibration data given in this report are not necessarily applicable for measurement of impulsive fields.

II. Description of the Test

The response of the tunable dipole antenna was calibrated in a standard field in the National Bureau of Standards (NBS) anechoic chamber. This field was generated by a transmitter and calibrated standard-gain antenna. The radiated electric field in the center of the beam was calculated, at the requested frequencies, in terms of the measured value of net transmitted power and the known value of the antenna gain. The effects of multipath reflections within the anechoic chamber have been analyzed and taken into account.

The tunable dipole antenna was mounted on a movable cart in the anechoic chamber and located on the axis (beam center) of the transmitting horn. A block diagram of the instrumentation used is given in figure 1 (see figure 6 in this Tech. Note). The value of the standard field used in the calibration was calculated from the equation

$$E = \frac{\sqrt{30\ PG}}{d} \tag{1}$$

Page 1 of 4
Test No. __________
Date of Test: ____________

where E = on-axis magnitude of the radiated field, volts/meter
P = net power delivered to the transmitting horn or OEG, watts
G = calibrated gain of the transmitting antenna, including appropriate near-zone correction factors, and
d = distance from the horn or OEG aperture to the calibrating field point (center of dipole) meters.

The antenna factor is the ratio of the field strength to the rf voltage from the antenna being calibrated, delivered to a 50-ohm receiver. Note that a lossless 50-ohm transmission line to the antenna being calibrated is implied in this definition of antenna factor.

The value of an unknown electric field strength can be determined with the calibrated tunable dipole antenna by measuring the output voltage of the antenna when connected to a 50-ohm impedance and using the following equation:

$$E = K + V \tag{2}$$

where E = electric field strength, dBV/m
K = antenna factor, dB, and
V = 50-ohm output voltage of the antenna, dBV.

Note: Units of dBμV/m and dBμV may also be used in the above equation for E and V respectively, if desired.

III. Experimental Data

The measured values of antenna factor for the dipole antenna are given in table 1. As requested, the antenna was calibrated in both the horizontal and vertical polarizations in the anechoic chamber. The measurements are normally done with horizontal polarization and those data are more reliable. The values given are for the antenna alone, independent of any interconnecting cable loss.

Table 1. Antenna factor for horizontal and vertical polarizations for Tunable Dipole Antenna, Requesting Company/Agency Name, Model ____, Serial No. ____.

Frequency (MHz)	Antenna Factor (dB) horizontal	vertical
200	14.0	14.3
250	16.0	15.9
300	17.5	17.7
400	20.0	19.9
500	22.0	22.2
600	23.6	23.5
700	24.9	25.0
800	26.1	26.0
900	27.1	27.3
1000	28.0	28.0

IV. Overall Calibration Uncertainty

For frequencies equal to or greater than 200 MHz, the dipole antenna was calibrated in an anechoic chamber. The electromagnetic field level was sufficient to determine the antenna factor of the antenna.

1. The largest source of error is uncertainty in the near-zone gain values of the transmitting antennas. The estimated possible error is ±0.5 dB.

2. Another source of error is uncertainty in the magnitude of multipath reflections within the anechoic chamber. Possible errors caused by chamber reflections are estimated to be less than ±0.2 dB.

3. Other sources of uncertainty are associated with antenna alignment, measurement of antenna separation distance, and NBS calibrations of the various instruments used. These include directional couplers, and incident and reflected power monitors. The overall error due to these latter sources is estimated to be less than ±0.3 dB.

The overall worst-case uncertainty of the calibration is the simple sum of those listed, or ±1.0 dB.

For the Director,
National Engineering Laboratory

Motohisa Kanda, Ph.D.
Group Leader, 723.03
Fields Characterization Group
Electromagnetic Fields Division

Test No. ________
Date of Test: ________
Reference: ________

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBS/TN-1309	2. Performing Organ. Report No.	3. Publication Date April 1987

4. TITLE AND SUBTITLE

NBS Calibration Procedures for Horizontal Dipole Antennas (25 to 1000 MHz)

5. AUTHOR(S)

D.G. Camell, E.B. Larsen, and J.E. Cruz

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This publication describes the theoretical basis and test procedures for horizontally polarized dipole calibrations at the National Bureau of Standards. Two different techniques and two different test sites are used. The standard antenna method uses the calculation of a field strength level, from the response of a simple half-wave dipole, to calibrate an antenna. This method is used at an open field site in the frequency range of 25 to 1000 MHz. The standard field method applies the theoretical gain equations of waveguides to determine the field strength level. This latter method is used in an anechoic chamber in the frequency range of 200 to 1000 MHz. Procedures for both techniques are explained and measurement setups are illustrated. Measurement uncertainties are discussed. Sample reports are included for both methods.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

anechoic chamber; calibration; dipole antenna; electromagnetic field; open field site; standard antenna; standard field

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